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COASTAL ENVIRONMENT SYSTEM AND ITS NUMERICAL SIMULATION II

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Synopsis

One of the most important factors of the water exchange under the stratified condition in summer at the Tanabe bay are internal Kyucho which amplification of internal tides and bottom intrusion and the meander of Kuroshio currents. And the meander of Kuroshio has impacts of the stratification and water quality at the Kii channel. Thus in this study we explored the relationship between Kuroshio migrations and the current and water quality at the Tanabe bay using the observation result and numerical simulation. As a result, the stratified structure at the Kii channel determines the structure of the current field and substance cycle in the Tanabe bay. Stratification at the Kii channel was determined by on or off migration of Kuroshio Current. The meander of Kuroshio is a most important factor water exchange system and substance cycle in the Tanabe bay.

Keywords: internal Kyucho, Kuroshio Current, water exchange, POM

1. Introduction

The Tanabe Bay (Fig.1) is located in the central part of Wakayama Prefecture, an entrance of the Kii Channel, facing the North-West Pacific Ocean. Shirahama Oceanographic Observatory, Disaster Prevention Research Institute (DPRI), Kyoto University is located in the inner part of the bay. A number of harmful red tide blooming has been observed in early summer to autumn since 1970s in the inner part of the bay because of active aquaculture in the semi-closed bay. The red-tide prediction project in the bay has been launched in 1997 as a joint research program of Shirahama Oceanographic Observatory and the Fisheries Laboratory of Kinki University.

According to observational results by the Tanabe Nakajima Storm Surge Observation Tower (DPRI's field research facility) located at the entrance of the bay, water exchange under the stratified condition in summer is done by amplification of internal tides and bottom intrusion of cold and high salinity water caused by coastal upwelling due to Ekman transport (Yoshioka at el, 1998). From the last year's observation, it can be found that when the Kuroshio moves toward the Kii Peninsula, the sea level rises and warm water intrudes in to the bay in the surface layer and block the cold water near the bottom (Niki, 2004).

According to Fujiwara at el (1997), at the Kii Channel in the summer, the fluxes of nitrogen and phosphorus from the outer ocean were equal to the fluxes from the land area into Osaka bay. And Takashi et al (2003) pointed out, the fluxes of nitrogen and phosphorus from the outer ocean was determined the meander of Kuroshio. It seems that the influence of on or off-cost migration of Kuroshio branch is important factor not only for the 3D characteristics of currents at the bay mouth but also the distribution of the water quality at whole bay. In this study we explored the relationship between Kuroshio migrations and the current and water quality at the Tanabe bay using the observation result. And POM-based computer simulation carried out for

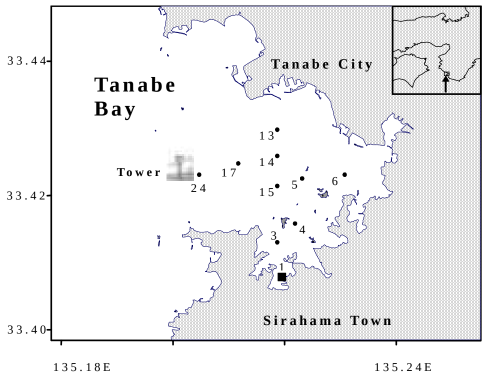

Fig.1 Measuring points on Tanabe Bay

better understanding of the circulation mechanism.

2. Observation of Coastal Water Environment in Tanabe Bay

According to Takeuch et al (1997), when south ward distance to the Kuroshio axis from Shionomisaki is less than 20 n.-miles, warm Kuroshio-surface water intrude into the upper layer of the Kii Channel. In the summer of 1999 Kuroshio-distance were less than 20 n-miles, on the other hand, in the summer of 2000 Kuroshio-distance was lager than 20 n-mails. On this basis, observation result in 1999 is used as typical data at the time of on shore migration of Kuroshio Current and observation result in 2000 is used as typical data at the time of off shore migration of Kuroshio Current.

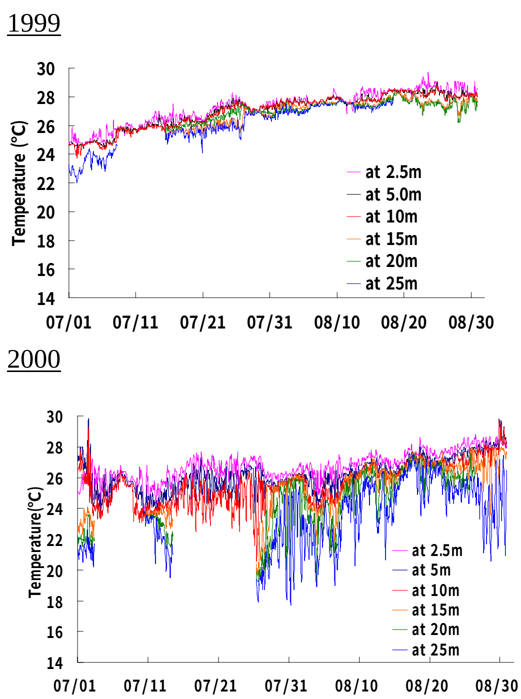

Fig.2 Time series of water temperature at TNSSOT

2.1 Observational results at the Tower

Oceanographic and meteorological measurements, (air temperature, air pressure, wind, solar radiation, wave, tidal height and water temperature) were conducted at the bay mouth with Tanabe-Nakashima Strom Surge Observation Tower (TNSSOT) of DPRI. Current profile was measured at the point of 30m in depth near the TNSSOT using ADCP (Acoustic Doppler Current Profiler of 1200kHz).

Figure 2 shows the temporal variation in water temperature distribution observed by the thermistor chain at TNSSOT from July to August in 1999 and 2000, in which sea water temperatures at 3, 5, 7･･･ 30m deep were measured. In 2000, remarkable event of rapid temperature drop near the bottom are observed. On the other hand, such a rapid temperature drop did not appear in 1999. There is a correlation between rapid temperature drop and surface wind. **Figure 3** shows the temporal changes in the 10-min averaged wind vectors observed at the point of 10m-height from MSL at TNSSOT. Wind speed or direction was not greatly difference between 1999 and 2000. The cause of such difference of distribution of water temperature is on/off-coast migration of Kuroshio branch.

Figure 4 shows the observation result of the vertical distribution of water current at the mouth of Tanabe Bay. This is the result on August 5th when the flood tide. When the east component (black circle) is positive, current is the inflow direction into Tanabe bay. The vertical profiles show the different trend both in 1999 and 2000. In 2000, the characteristic of the internal wave, upper current inversed lower current, was appeared in observation result. But in 1999, the characteristic of internal wave was weak. As the current was same direction in all layers, the peak intensity is a little bit small in 1999. The current in the bottom layer in 1999 was smaller than in 2000. Thus in 2000 cold water often intrude into the bay in the bottom layer during the flood tide, while in 1999 the warm water were inflow into the bay in all layer during the flood tide. The cause of such difference is

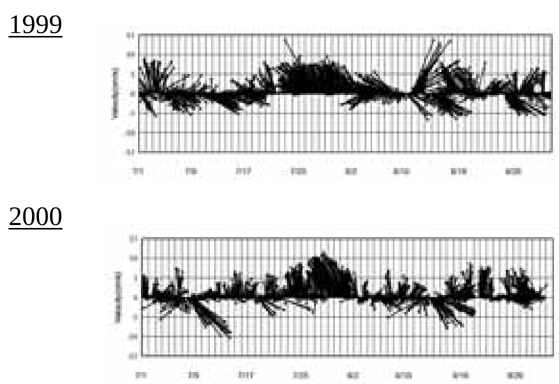

Fig.3 Stick diagram of winds at TNSSOT

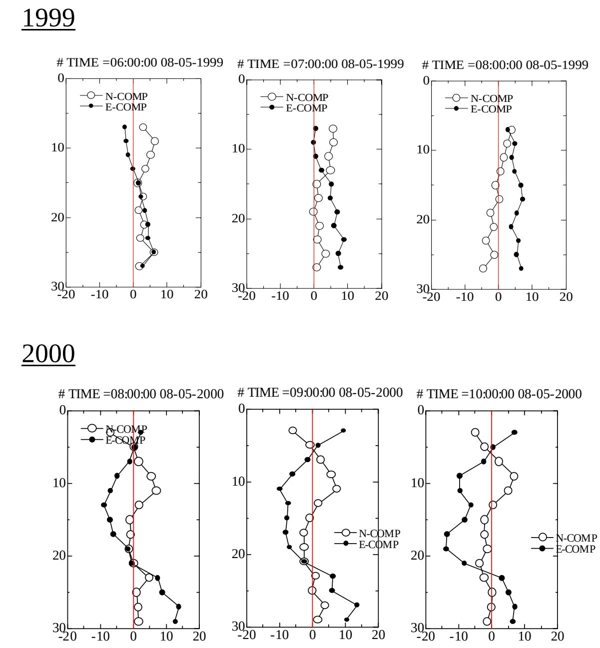

Fig.4 Vertical distribution of current profile during flood tide at TNSSOT

the difference of stratified structure at the Kii channel.

Figure 5 shows the vertical distribution of water temperature and σt at the Kii channel in August 1999 and 2000 (Wakayama Research Center of Agriculture , Forestry and Fisheries, 1999 2000). The difference both in 1999 and 2000 is large at 130m depths or less. The value of water temperature in 1999 is higher than in 2000. In 1999, the gradient of the water temperature value is large less than 130m, while in 2000, the gradient is large at 50m or less. The value of σt in 1999 is lower than in 2000. There is a thermo cline at the 50m depths in 2000, while in 1999 thermo cline was not clear.

2.2 Observational results at the inner part of the bay

The water quality (water temperature, salinity, chlorophyll-a and dissolved oxygen) was measured using CTD (Sea-Bird-Electronics SBE-25) near the aqua culturing raft of Kinki University (St.3 in **Fig.1**,). The observation period was Jury 21st to August 17th in 1999 and July 25th to August 11th in 2000. **Figure 6** shows the time series of the observation result using CTD at the ST.3 in 1999 and 2000. In 1999 water temperature was hot in all layer because on-coast migration of Kuroshio currents. It rained from August 10th to 13th, the value of salinity in the surface layer is low around August 12th. The value of chlorophyll-a was very low during observation period and the concentration of dissolved oxygen was low near the bottom. In 2000, remarkable events of rapid temperature drop and salinity rise near the bottom were observed on days of July 26 and August 3 and 8. In 2000, Kuroshio axis was far from the Kii peninsula and cooler and saliner water intruded into the lower layer of the Kii channel from the subsurface on the shelf. This event cause of inflow from the lower layer of the Kii channel and is related to the dissolved oxygen and chlorophyll-a. After this event, the value of dissolved

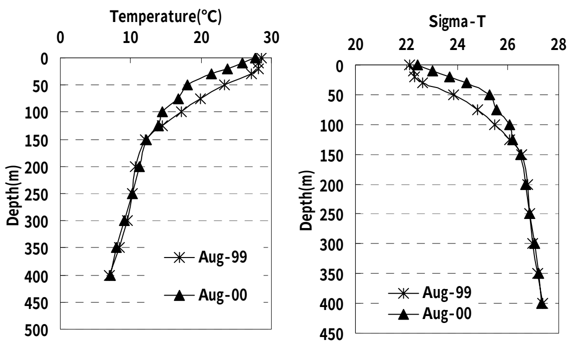

Fig.5 Vertical distribution of water temperature and σt profile in1999 and 2000

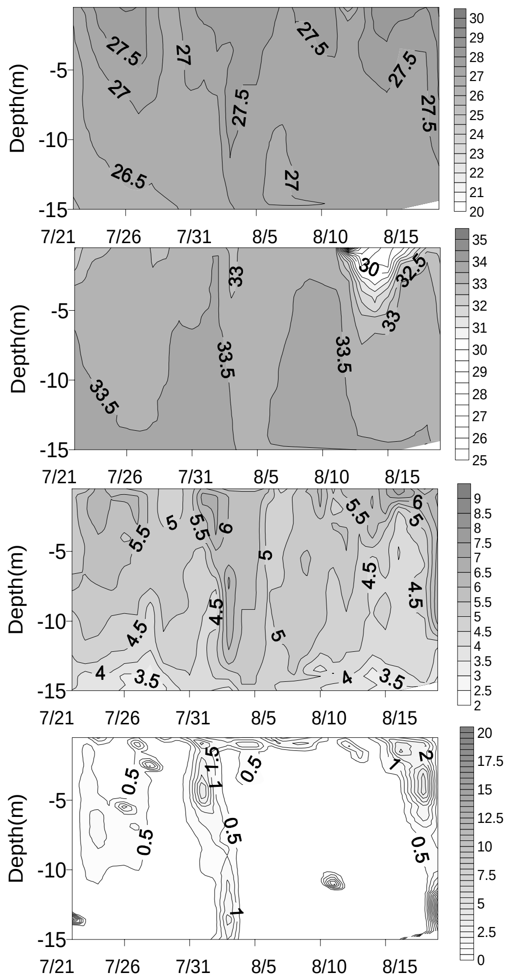

Fig.6 (a) Time series of the observation result using CTD at the ST.3 in 1999

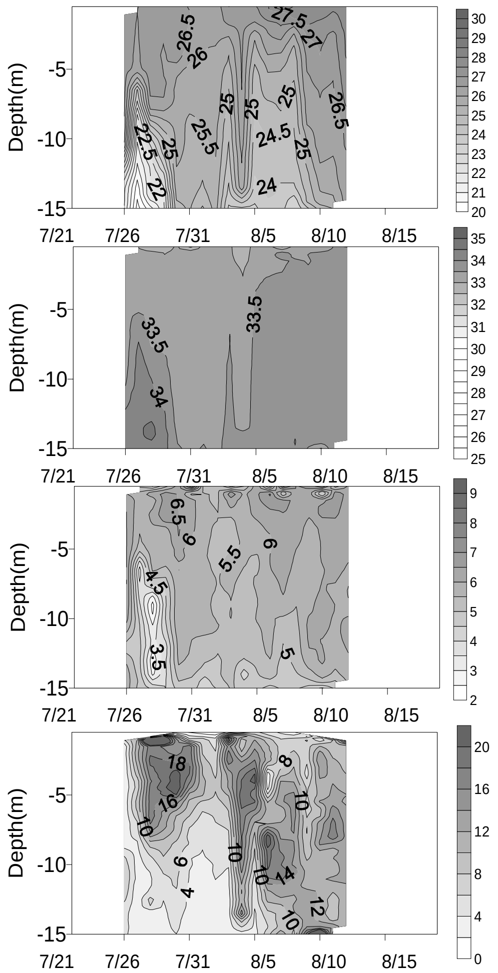

Fig.6 (b) Time series of the observation result using CTD at the ST.3 in 2000

oxygen was decrease and the chlorophyll-a was increase.

Figure 7 shows the time series of the current profile in the bottom layer using electromagnetism current meter at the ST.3 (Fig.1). It is the same period of the CTD observation. The south direction currents indicate inflow into inner part of the bay. In 2000 south current often occurred, while in 1999 there are few south current exceed 5 cm/s. The difference of the current structure at the Tower has influenced inner part of the bay.

From the Fig.6 and Fig.7, when south current did not appear in 1999, the dissolved oxygen showed low value in the bottom layer. At the inner part of the bay, when the flow is small, it seems that the value of dissolved oxygen has a tendency to decree from bottom layer. On the other hand, when south current appeared in 2000, the value of dissolved oxygen was decrease. When the Kuroshio Current is off coast migration, for the water temperature is low, the value of dissolved oxygen of the water intruded from the lower layer of the Kii channel is low. The strong current near the bottom in 1999 overcome the anoxic water, while the strong current near the bottom in 2000 is the growth of oxygen depression.

The water quality of the lower layer of Kii channel was not only cooler and salier but also contained a lot of nutrient. The concentration of nutrient at the lower layer of the Kii channel has high correlation with the temperature. **Figure8** shows the correlation between the concentration of nitrate and temperature at the ST.3. It is notice that there were few observation of nutrient and the influence of land area caused of rain was removable. In 2000, water temperature and nutrient make negative correlation less than 25 ℃. It is same trend at the Kii channel. Clearly, the water mass of lower layer at the Tanabe bay in 2000 was transported the lower layer of the Kii channel by strong current near the bottom. While in 1999 warm Kuroshio surface water intruded into Tanabe bay in all layer.

As mentioned above, in the Tanabe bay, the stratified structure in the Kii channel will have determined a vertical current profile and inflow water quality. Furthermore the structure of current field and substance cycle are also provided at the inner part of the bay. It is noticed that these discussions are only based on the data fragments, such as ADCP data at the bay mouth and the CTD observation at the ST.3. To understand the influence of the structure of density stratification, we may need the aid of

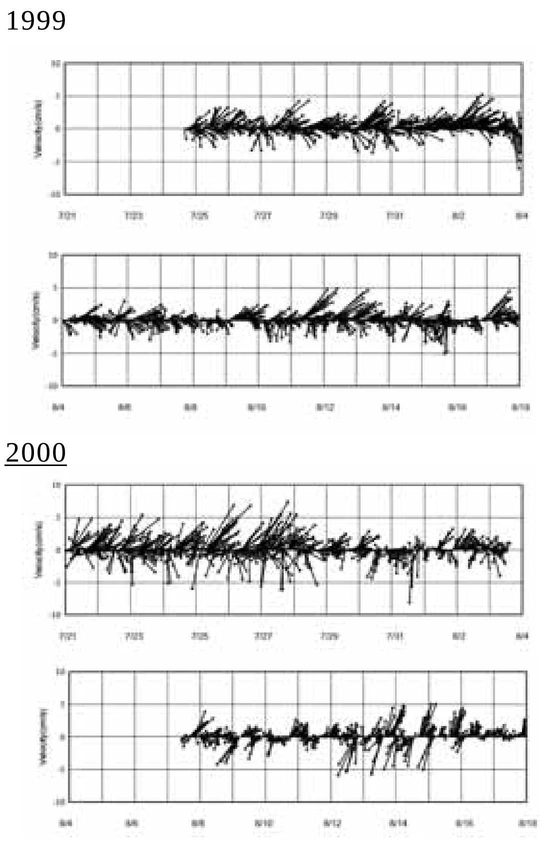

Fig.7 Time series of the current profile in the bottom layer at the ST.3

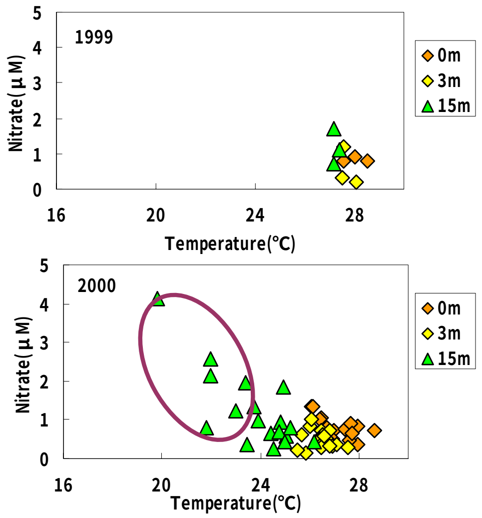

Fig.8 Correlation between the concentration of nitrate and temperature at the ST.3

numerical model

3. Numerical Experiment

3.1 POM modification

Current field and scalar transportation are simulated by the Princeton Ocean Model (POM), which is open-domain software to simulate ocean circulation. POM is fully three-dimensional model with free surface in the sigma coordinates. Its basic equations and a more extensive discussion of the features of model can be seen in the reference of Blumberg and Mellor (1987).

To overcome the numerical error in computing the horizontal pressure gradient forcing in water temperature and salinity computation, we use the method by Stelling and van Kester (1994) before study. Stelling and van Kester (SVK) method is the revision method for the calculation of horizontal pressure gradient in sigma coordinates models. Its method is worth but computing cost is high because of computation algorism is complicated. The basic idea of SVK method is to change the rectangular grid system from sigma coordinate grid system. Then the positions of the density point are identical in the two systems. If the staggered grid arrangement is introduced, the position of the density point different from the position of the pressure gradient point, which have to estimate to compute the pressure gradient force. The positions of the pressure gradient point are not identical in the two systems. Thus in the SVK method it is necessary to transform the computed pressure gradient force into original grid system from new grid system. In order to omit this process, the center of redefined grid system is employed not the density point but the pressure gradient point. It is simple improvement, but computation cost is cut down.

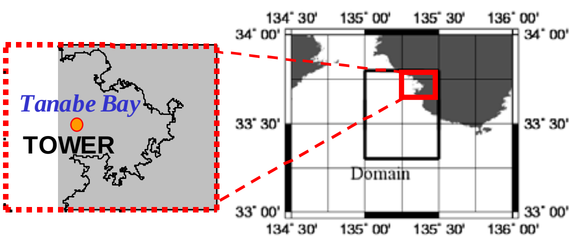

Fig.9. Computation domain

Computation domain is the west side of Kii peninsula including Kii channel (**Figure.9**). Horizontal grid size is 1min and the number of vertical layer is 31. The vertical distribution of water temperature and σt shown in Fig.5 was given as initial condition. The astronomical tide level computed NAO model (Matsumoto, 2000) was given on the boundary condition. Computation period is 8 days and first 3 day was not done the temperature and salinity computation to spread the flow inner part of the bay. In order to generate the coastal upwelling, north wind (3m/s) was blow for 2 days (from 7th to 8th) after south wind (2m/s) for 3days (from 3rd to 5th).

3.2 Results and discussions

Figure 10 shows the computation result of the vertical distribution of east-west direction water current at the mouth of Tanabe Bay. This is the result after 7 days when the north wind blowing started. The vertical profiles show the similar trend to the observation result. In 2000, the characteristic of the internal wave, upper current inversed lower current, was appeared in computational result. But in 1999, the characteristic of internal wave was weak. **Figure 11** shows the computation result of the distribution of

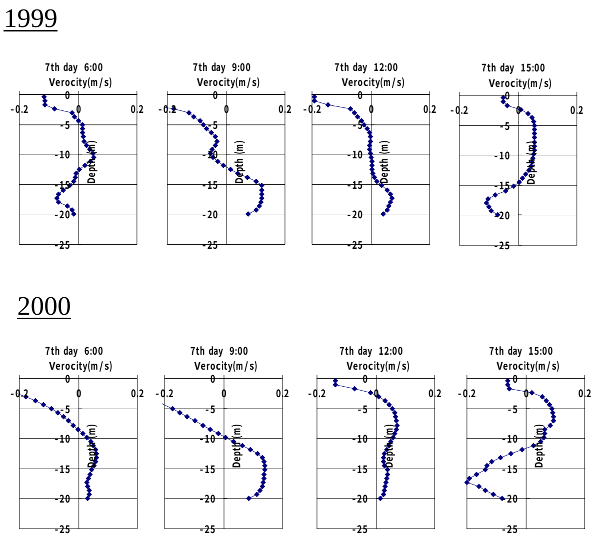

Fig.10 Vertical distribution of water current at the mouth of Tanabe Bay

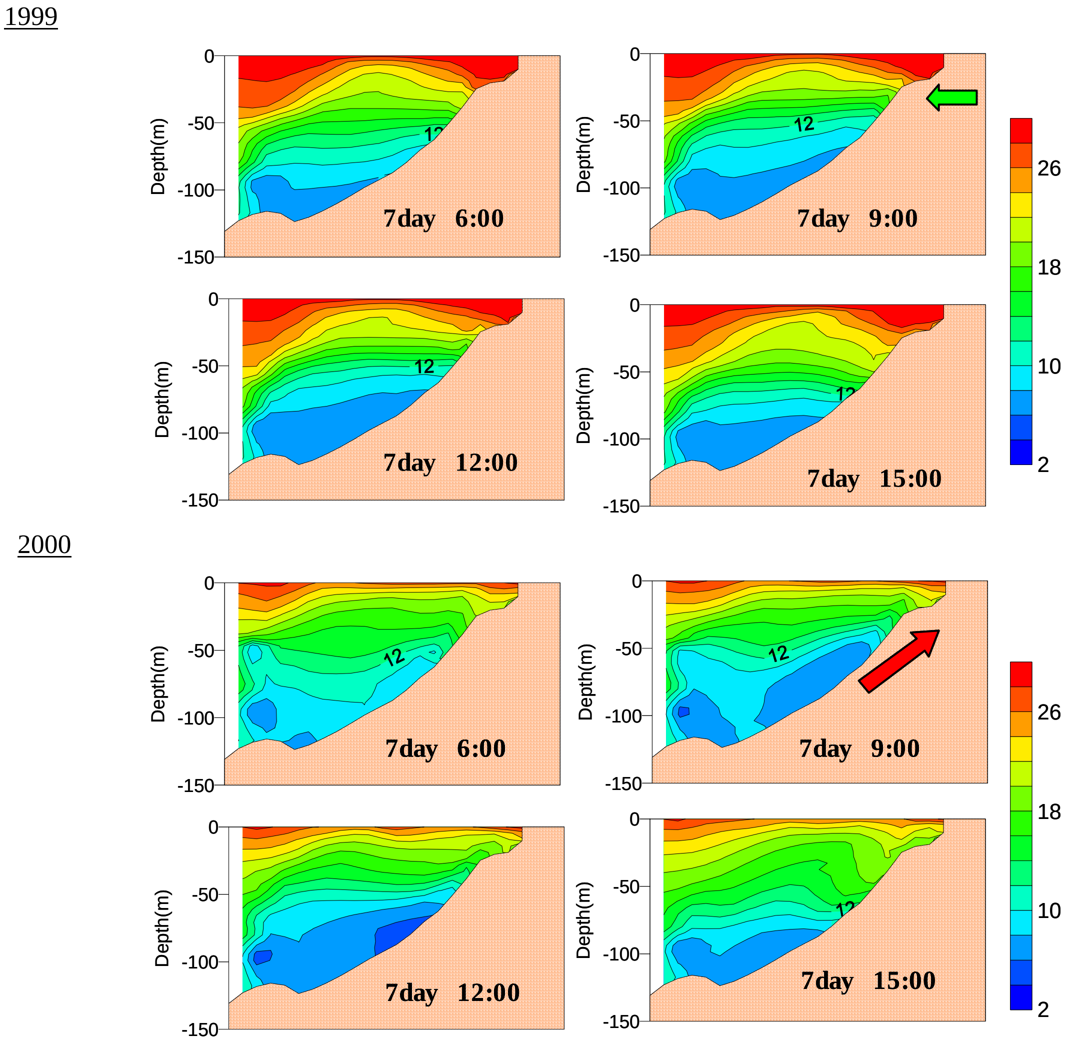

Fig.11 Computation result of the distribution of water temperature along the east-west line in Kii channel

water temperature along the east-west line in Kii channel. East side is Tanabe bay. It is a same period Fig.10. In 2000, coastal upwelling along the sea bead is reproduced. While in 1999, coastal upwelling is blocked by warm surface water. The model roughly predicts rapid temperature drop caused by the bottom intrusion of cold water in 2000 and warm surface water intrusion in 1999. This result offer support for the conclusion obtained from the observation, that is, the stratified structure in the Kii channel determine the structure of the current field and substance cycle in the Tanabe bay. Stratification at the Kii channel was determined by on or off migration of Kuroshio Current. The meander of Kuroshio is a most important factor water exchange system and substance cycle in the Tanabe bay.

4 Conclusions

1. In 2000, the characteristic of the internal wave, upper current inversed lower current, was appeared in observation result of vertical profile at the Tower. But in 1999, the characteristic of internal wave was weak. Thus peak intensity of water current near the bottom at the tower in 1999 little bit small.
2. From CTD observation at the inner part of the bay, in 1999 which is on coast migration of Kuroshio currents water temperature was hot in all layer and the value of salinity was high except rainy day. The value of chlorophyll-a was very low during observation period and the concentration of dissolved oxygen was low near the bottom. While in 2000 which is off coast migration of Kuroshio currents, remarkable events of rapid temperature drop and salinity rise near the bottom were observed on days of July 26 and August 3 and 8. After this event, the value of dissolved oxygen was decrease and the chlorophyll-a was increase.
3. According to current observation in the bottom layer at the inner part of the bay, in 2000 south current often occurred, while in 1999 there are few south current exceed 5 cm/s. Considered with CTD observation, the strong current near the bottom in 1999 overcome the anoxic water, while the strong current near the bottom in 2000

is the growth of oxygen depression

4. In 2000, water temperature and nutrient make negative correlation less than 25 ℃. It is same trend at the Kii channel.
5. The model roughly predicts rapid temperature drop caused by the bottom intrusion of cold water in 2000 and warm surface water intrusion in 1999. This result offer support for the conclusion obtained from the observation, that is, the stratified structure in the Kii channel determine the structure of the current field and substance cycle in the Tanabe bay. Stratification at the Kii channel was determined by on or off migration of Kuroshio Current. The meander of Kuroshio is a most important factor water exchange system and substance cycle in the Tanabe bay.

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海域環境システムとその数値シミュレーションに関する研究II

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要　旨

田辺湾における夏季成層時の海水交換に対しては内部波と沿岸湧昇の結びついた内部急潮が重要であると認識されている．一方黒潮の離接岸は田辺湾の面する紀伊水道の成層構造や水質に影響を与える．本研究では特に黒潮の離接岸に注目し田辺湾への影響に関して観測結果や数値モデルを利用して考察した．その結果，紀伊水道表層付近での成層構造は田辺湾全体の流動構造と物質循環を決定している事が分かった．紀伊水道の成層構造は黒潮の離接岸の影響を受けており，田辺湾での海水交換やそれに伴う物質循環にたいして黒潮の離接岸が与える影響が大きい事が確認された．

キーワード:内部急潮，黒潮，海水交換，POM

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河川・海岸系での物質輸送モデル（5）　沿岸域での陸水，外洋水の影響のモデル化

○ 仁木将人･山下隆男

1.　はじめに

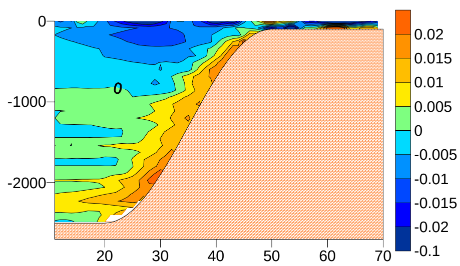
沿岸域は海岸線をはさみ陸域と海域を併せ持つ価値の高い空間として古来より利用されてきた．しかし，高度経済成長期以降，人間活動の影響を受けその環境悪化が問題視されるようになり，特に閉鎖性内湾での富栄養化が社会問題となった．富栄養化対策として，陸域からの汚濁負荷削減のための様々な施策が実施される一方，近年，外海からの栄養塩流入が陸域からの負荷量に匹敵する（藤原ら，1997）といった報告も見られ，沿岸域への外海からの影響が無視できないものであると認識されるようになってきている．従って沿岸域での物質輸送モデルを構築する場合陸水，外洋水の影響を取り込む必要があるが，陸域や外洋の影響を簡易に考慮するモデルがほとんどである．そこで本研究では陸域海域カップリングモデルを構築し，また，外洋からの影響に関しても地球フロンティアでの計算結果を取り込む陸水・外洋水カップリング型海洋モデルの開発を行う．

ところで和歌山県の田辺湾では，夏期における湾内での海水交換機構解明のため，1998 年から海域環境モニタリングが行われるようになり，現在 7 年目を向かえている．これまで，北東風に起因する外洋水の進入が内部潮汐と結合する内部急潮（吉岡ら，1998）が，湾奥での植物プランクトンの増減の支配因子の一つであることが確認されている（朴ら，2003）．また昨年度は観測結果から湾内の海水交換機構に対する整理を行い，湾の水交換に対して風や気圧といった気象条件とともに黒潮 2 次流の影響が重要である事が分かっている（Niki，2004）．そこで，開発したモデルを和歌山県の田辺湾での観測結果の追算へ適用し観測結果との比較から有効性を検討する．

2.　モデルの概要

陸域モデルとしては米国 EPA によって開発された統合型流域環境管理モデルである HSPF を使用する．HSPF は，時系列の降雨，温度，蒸発散等の気象データ及び，土地利用状況や土壌の性質等に由来するパラメータに基づき，流域における水文学的・水理学的過程だけでなく土地表層、土壌内、流水中における水質的な諸過程について統合的に再現することが可能である．

海域モデルとしてはプリンストン大学により開発された POM を使用する．POM は地形追従性の良いσ座標系を採用し，2 次元と 3 次元で時間間隔を変える mode splitting 手法を利用するといった特徴がある（Mellor，2003）．σ座標系は海底地形形状の再現性に優れるが，急勾配の地形での物質の移流･拡散を計算する場合，hydrostatic inconsistency と呼ばれるグリッドの歪みにより，実際には生じない密度勾配が生じ，水平圧力勾配や水平拡散勾配の計算に誤差が発生する．田辺湾では内部波による水交換が外洋からの影響の一つの鍵となっているため，こうした数値誤差の緩和が必要である．σ座標に起因する数値誤差に対しては，古くから様々な手法が開発されてきている．Gary（1973）は，基準密度を設定しそこからのズレとして計算する方法を提案し，POM ではこの手法を利用している．その他，圧力勾配項を高次の差分形式で表現するものや（McCalpin，1994；Chu and Fan，1997），密度に関して z 座標系に再定義し z 座標系で圧力勾配項を算定する方法（Stelling and Van Kester，1994；Slordal，1997），グリッドの歪みを考慮した差分スキーム（Song，1998；Shchepetkin and McWilliams，2003）等がある．講演では，誤差緩和法に関して詳しく比較検討を行う．



計算結果（図は水平流速の分布）